TENSILE TEST OF CORED REPAIR MATERIAL FROM NEWPORT BRIDGE PIERS

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by:

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RESEARCH AND TECHNOLOGY

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Acknowledgements

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I would especially like to express my appreciation to Robert Mechnig of Meckandil Tools for working with us to machine the components for the specimen mounting and the removal tool. As always, he was very accommodating.

And finally to Peter Janeros: Once again with the interesting problems! At least it allows us to broaden our horizons. I would also like to thank Peter for purchasing the test fixtures for us.

Introduction

The Research and Technology section was contacted by the Rhode Island Turnpike and Bridge Authority (RITBA) regarding some repair work done on the concrete piers of the Newport Bridge. The existing concrete was placed in 1968, with a design strength of 3,000 psi. The product used for the patching requires that the substrate be saturated surface dry (SSD) prior to application. This prevents the existing concrete from absorbing water from the mortar and leaving less for the hydration process. This could cause weakening of the mortar at the interface to the substrate and result in a poor bond. On the earlier portion of the work, there was some concern that a saturated condition was not sufficiently achieved and therefore not in accordance with the manufacturer's recommended procedure.

It was decided to collect cores from several of the repair sites, with half from the locations of concern and the remainder from sites where the preparatory work was known to have been done correctly. These would be tested in tension through the long axis of the cores to determine the relative bond strength of the two groups and the overall strength of the repair[1].

Procedure

The specimens were received from RITBA and photographed (Figures 1, 3 through 9). RITBA did not identify which specimens were from the suspect areas, to prevent any bias being developed by the individuals performing the testing. The repair material had been placed six to eight weeks earlier and had therefore cured well in excess of 28 days prior to testing. The arrow indicates the top of the core and the line around the circumference indicates what was considered to be the interface between the substrate and the patch. The specimen characteristics were then recorded (see Initial Observations). The specimens were trimmed on each end, to create a cylinder with parallel ends perpendicular to the long axis of the cores, after which they were photographed again (Figure 2).

[1] The manufacturer of the repair system specifies a bond strength of 2200 psi (with the mortar scrubbed into the substrate) and a splitting tensile strength of 500 psi after 28 days, but this requires lab specimens prepared in accordance with ASTM C-882 and C-496, respectively. Since the samples provided were from an actual installation, these test methods were not appropriate. Therefore, comparative testing was deemed to be the best way to determine the adequacy of the repairs in the areas of concern.

The department does not perform tensile testing of concrete, so a system had to be developed to mount the specimens in the Materials Section's Tinius-Olsen load frame (see cover photo), which has a tensile loading capacity of 60,000 pounds[2]. It was decided to bond two thick steel plates to the ends of the trimmed cores. The plates have holes on the face opposite the cores, tapped to accept threaded rod. The threaded rod was then run through steel plates bolted to the upper and lower heads of the load frame and secured with a nut and washer on each rod (Figures 13 and 14).

Prior to testing the RITBA samples, a spare untested compression cylinder[3] was cored to create specimens to check the setup of the apparatus and confirm that the adhesive[4] was adequate for the application. Three samples were created and cut square on each end. The specimens were then bonded to the plates. Special care was taken make certain that the assembly was aligned such that it would load through and parallel to the longitudinal axis of the cores (Figures 10 through 12). The specimens were loaded using the method as described above and the failure mode indicated that the system would provide accurate results. The machine was set to the low range of 1,800 pounds force. The failures ranged from 500 to 1040 pounds (208 psi to 432 psi), somewhat lower than expected[5], but all of the breaks occurred in the concrete, not the epoxy. The lower breaks may have been due in part to the loading rate. Based on the rates used for these specimens, it was decided that a maximum rate of 250 pounds/minute would used for the RITBA cores. This was considered sufficiently slow to avoid a high rate of strain and shock loading the concrete to premature failure. Photos of the fracture faces of the specimens can be seen in Figure 15.

Using experience gained during the setup of the preliminary test specimens, a method was developed for positioning the RITBA cores to obtain proper alignment. V-supports were fashioned out of aluminum sheet metal (Figure 16). They have the advantage of being easily modified to adjust for slight variations in the cores. This allowed the cores to be leveled to center the core on the loading axis (the center of the tapped hole). Once the epoxy had been applied[6], the end plates were carefully squared relative to the long axis of the specimens while the adhesive was still workable.

[2] Calibrated on October 6, 2004
[3] From a RIDOT construction project; with a 5,000 psi compressive strength for the batch.
[4] 3M Scotchweld DP-420 Epoxy.
[5] The tensile strength of concrete is usually taken to be 1/10 of the compressive value.
[6] A mixing nozzle was used to insure proper blending of the components.

After allowing the epoxy to cure, the specimens were loaded using the same procedure used for the preliminary specimens. All specimens were oriented so that the repair material was at the top during loading. The machine loads and loading rates were recorded and the type of break was noted. The broken cores were then photographed.

Initial Observations

All cores were 1.75 inches in diameter, with the repair mortar a darker gray than in the original concrete. There was no visible discrete boundary between the patch and the substrate, indicating that there was no delamination even after coring and removal. The top surface of the cores showed a wood grain pattern, indicating that the repairs were of the form and place method. Notes for the individual cores (prior to any preparatory work) are as follows:

Core#1 – 0.75 inch thick patch with 0.5 inch nominal aggregate, not easily discernible from 1 inch nominal aggregate original concrete w/mortar color main indicator of terminus, total core length 4.5 inches. Bag Markings: #1, N, N. Beam, 5E, WF, Hit Steel

Core#3 – 4.5 inch thick patch with 0.5 inch nominal aggregate, not easily discernible from 1 inch nominal concrete w/mortar color main indicator of terminus, total core length 8.5 inches. Bag Markings: #3, N, 3N, 5E, West Face Strut.

Core#4 – 1.25 inch thick patch with 0.5 inch nominal aggregate, more easily discernible from 1.5 inch nominal aggregate original concrete w/coarse aggregate in substrate shows terminus, total core length 5.5 inches. Bag Markings: #4, N, 3E, West Side Strut.

Core#5 – 4.5 inch thick patch with 0.5 inch nominal aggregate, more easily discernible from 1 inch nominal aggregate original concrete w/mortar color main indicator of terminus, total core length 5.25 inches. Bag Markings: #5, O, SB, 9E, W. Face.

Core#8 – 2.75 inch thick patch with #8 nominal aggregate (see Figure 9), very easily discernible from 1.5 inch nominal aggregate original concrete w/patch aggregate size main indicator of terminus, but mortar color difference is distinct, total core length 6 inches. Bag Markings: #8, O, SB, 9E, E. Face.

Core#9 - 2.875 inch thick patch with 0.5 inch nominal aggregate, very easily discernible from 1.25 inch nominal aggregate original concrete w/coarse aggregate size in substrate main indicator of terminus, total core length 6.5 inches. Bag Markings: #9, O, NB, 7E, EF.

Because there was substantial variability in the cores, they were not cut to a uniform length. Trying to use a fixed aspect ratio would have created inconsistent properties for the specimens (patch to substrate thickness, aggregate size to matrix thickness), which would have eliminated any advantage in having the same length for all specimens. Note that the repair material/substrate interface was not typically a flat plane perpendicular to the axis[7]. These variables had the potential to add some complexity to the analysis of the results.

[7] Cross-sections of hills and valleys seemed evident upon close examination.

Figure 1 – Test Specimen Cores

Figure 2 – Test Specimen Cores After Cutting to Square

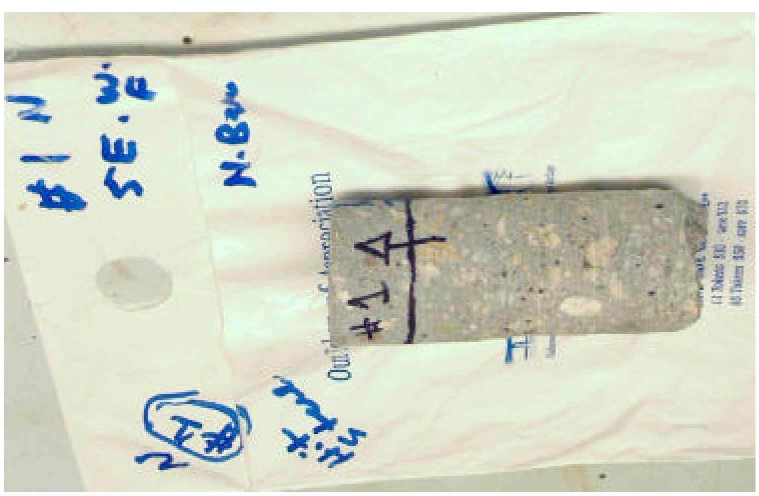

Figure 3 – Specimen 1 (uncut)

Figure 4 – Specimen 3 (uncut)

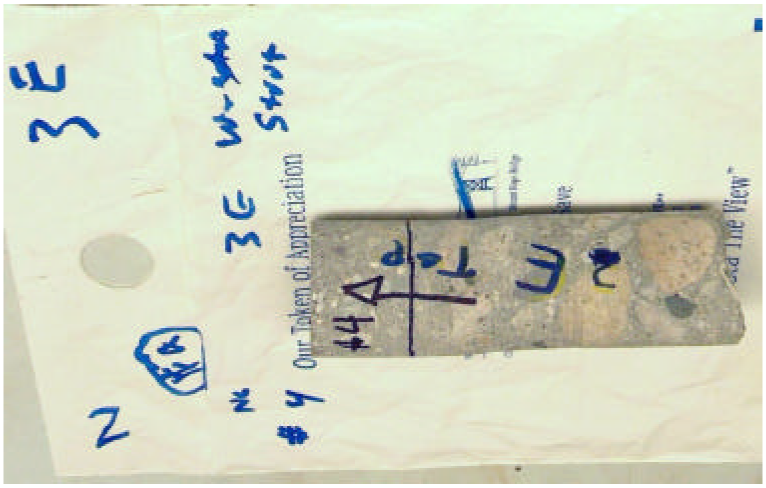

Figure 5 – Specimen 4 (uncut)

Figure 6 – Specimen 5 (uncut)

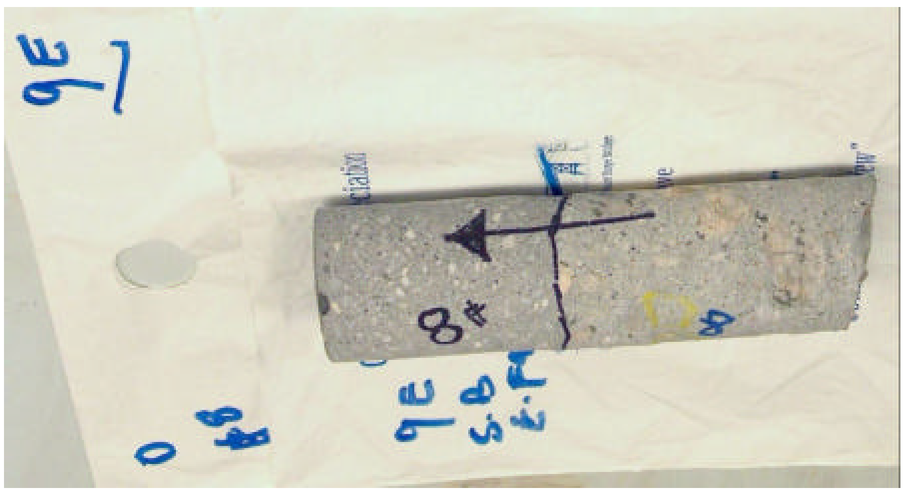

Figure 7 – Specimen 8 (uncut)

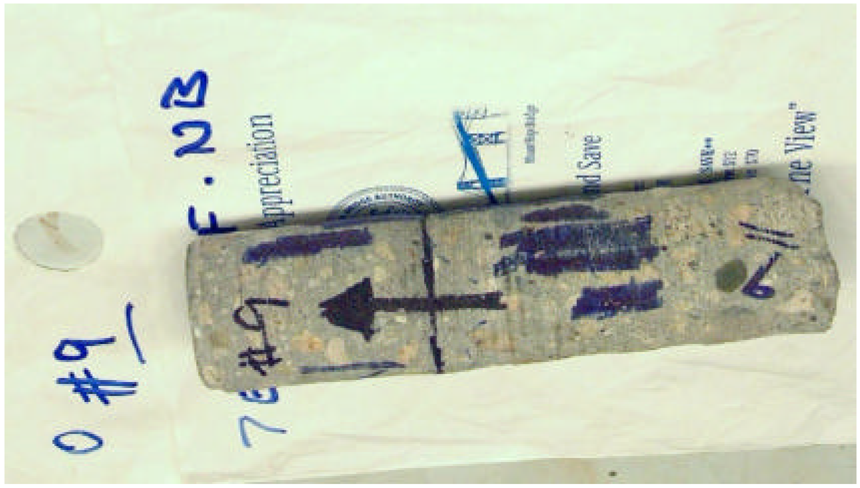

Figure 8 – Specimen 9 (uncut)

Figure 9 – Repair Material Aggregate Difference (Upper Section of Cores) between Core #8 and Other Cores (Core #5 Typical of Remaining Cores)

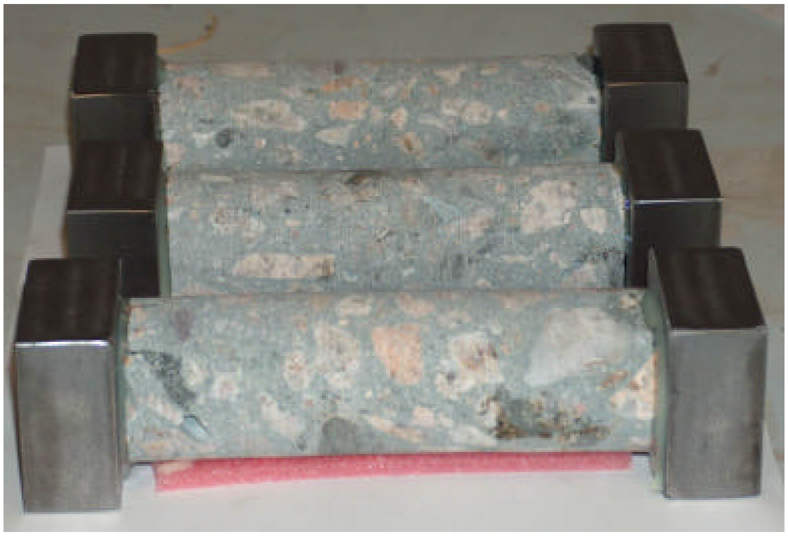

Figure 10 –Preliminary Test Specimens

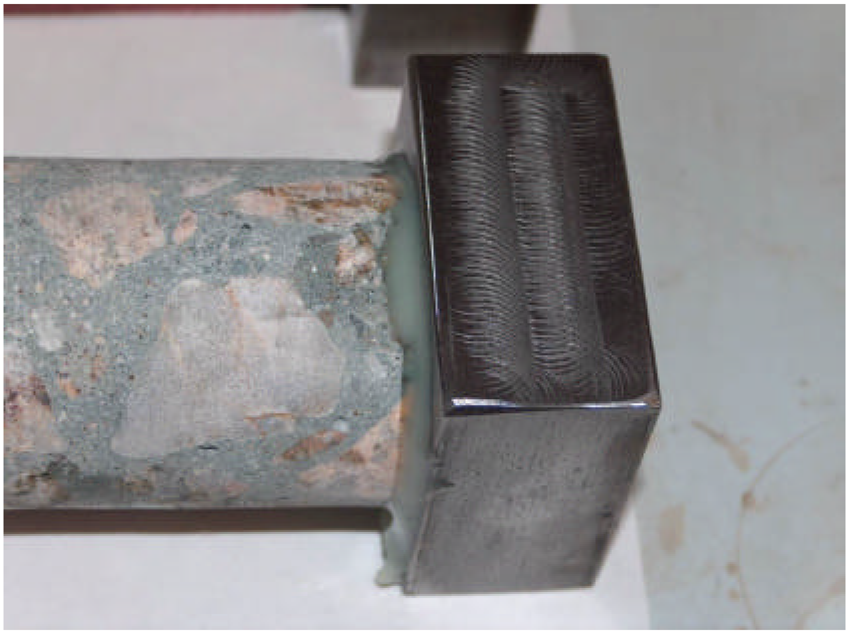

Figure 11 – Preliminary Specimen with Closeup of Epoxy Bond

Figure 12 – Full Test Assembly with Preliminary Specimen

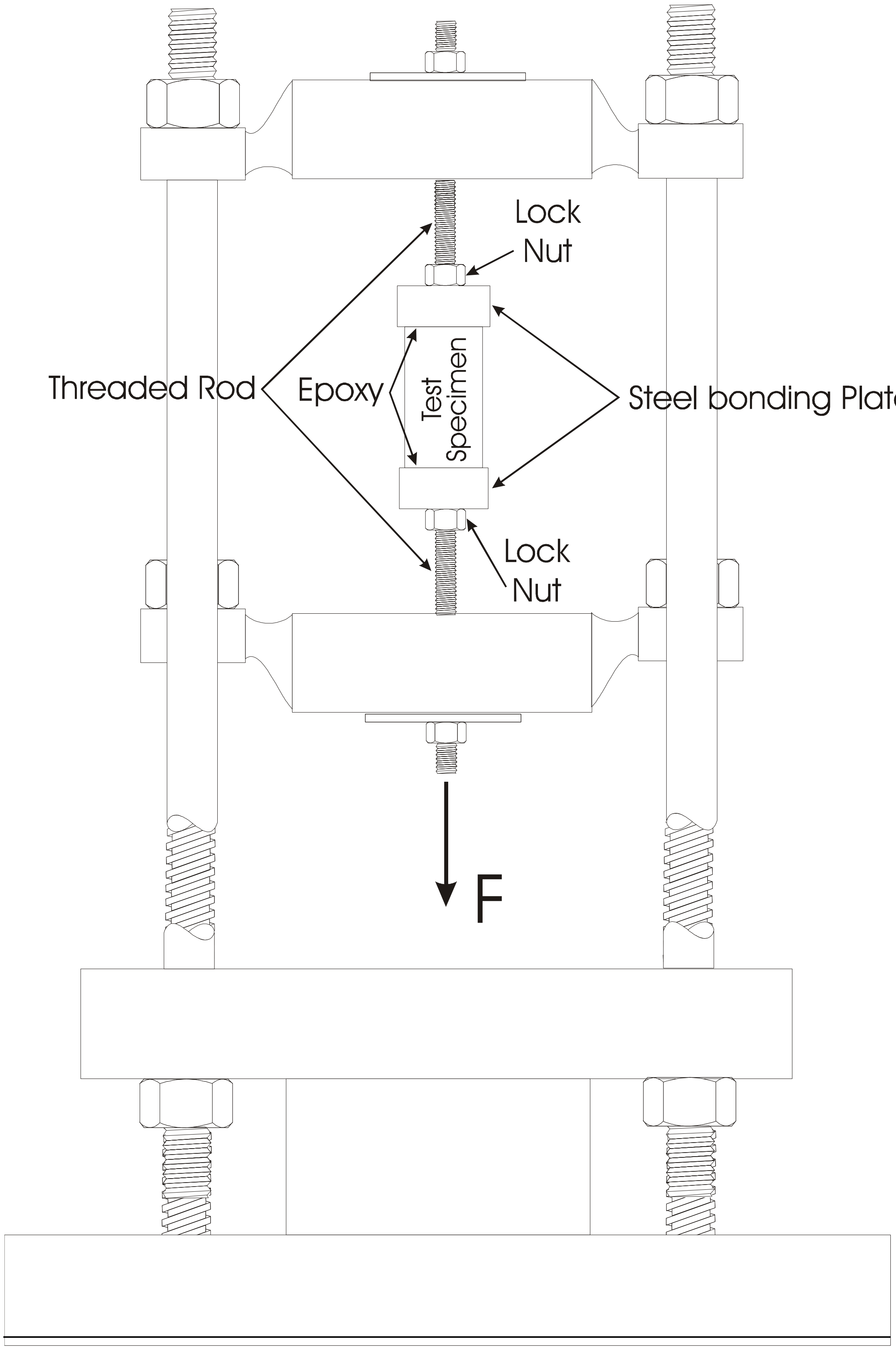

Figure 13 – Load Frame and Specimen Rig

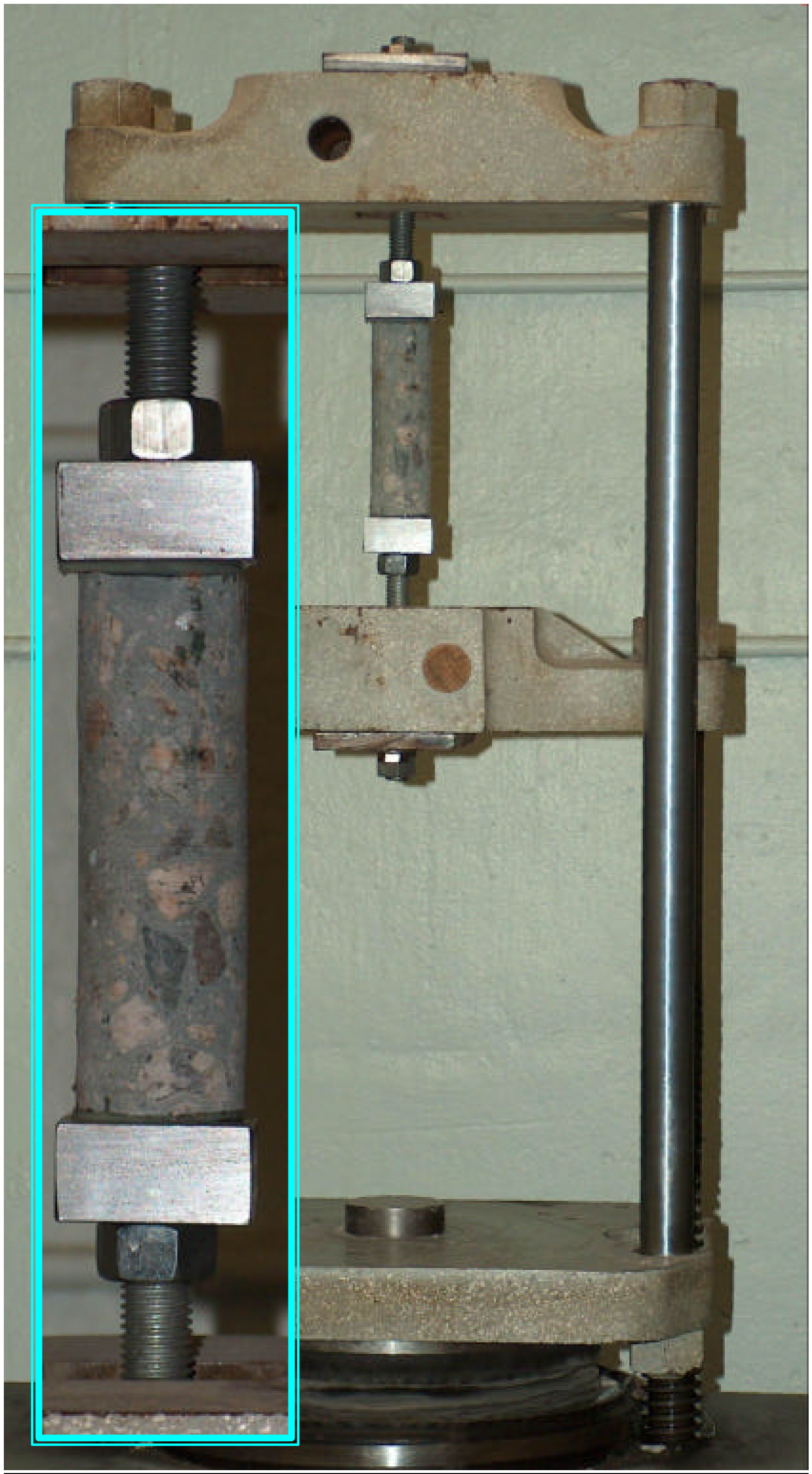

Figure 14 – Test Rig in Load Frame (Inset - Test Rig Close View)

Figure 15 – Top Photo: Fracture Faces of Preliminary Specimens, Bottom End Upright; Bottom Photo: Fracture Faces of Preliminary Specimens, Top End Upright

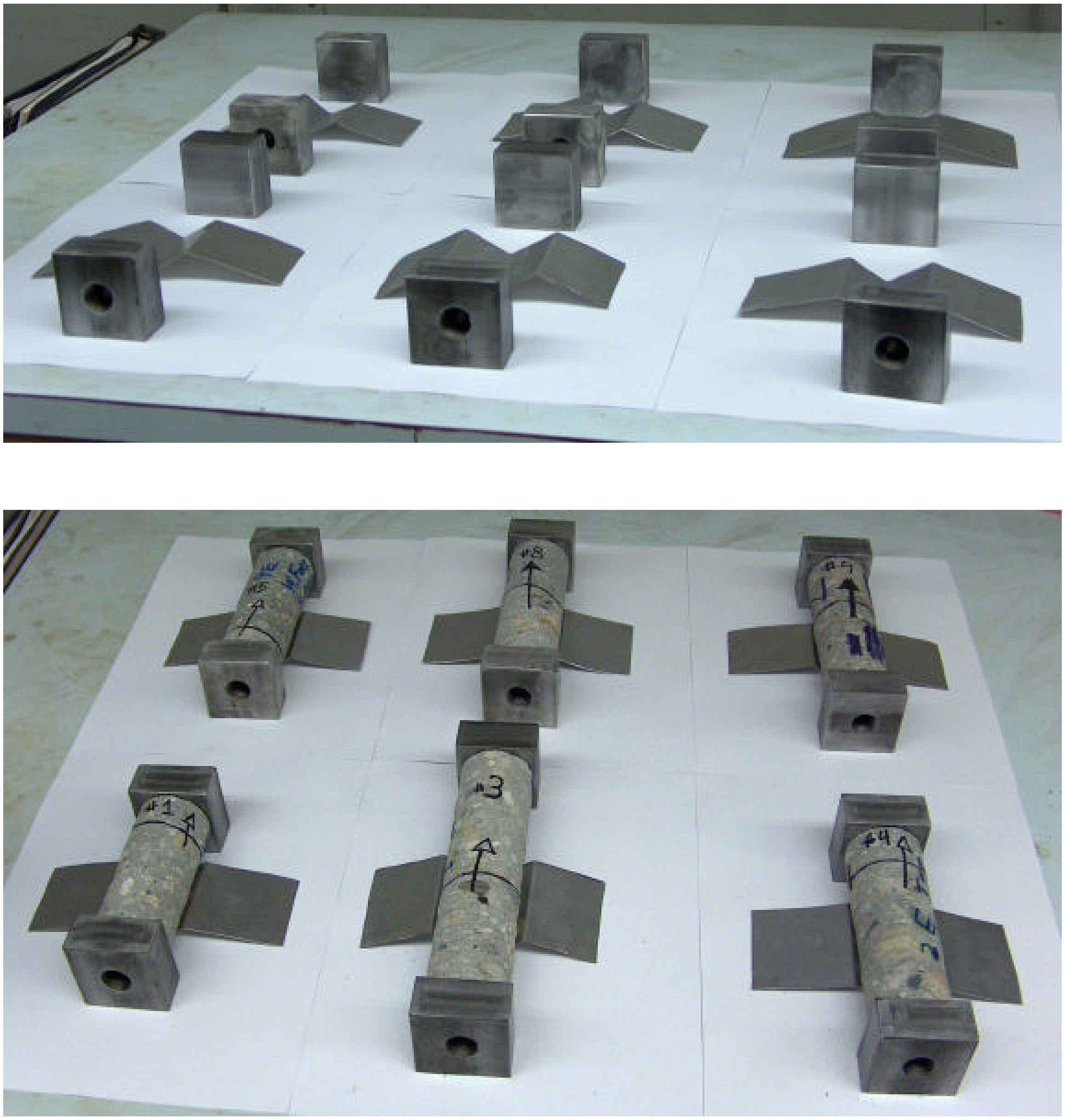

Figure 16 – Specimen Setup Positioning

Results

Of the six specimens tested, one failed in the substrate. The remainder separated through the patch/substrate interface (as estimated by the investigator). Table 1 gives the specifics for the testing. Figures 17 through 22 show the breaks. The machine was recently calibrated, including for the loading rate. The variations in the rate may have been due to difficulties in adjustments at the low range used and the very low rate considered necessary. Since the maximum pounds/minute was not exceeded, this was not believed to be a problem.

Specimen No.	Machine Load (lbs)	Tensile Strength (psi)	Loading Rate (lbs/minute)	Break Location
1	388	161	100	Substrate
3	412	171	120	Patch/Substrate Interface†
4	50	21	n/a	Patch/Substrate Interface†
5	384	159	150	Patch/Substrate Interface†
8	480	199	150	Patch/Substrate Interface†
9	420	174	75	Patch/Substrate Interface†

†The failure occurs through the plane of the interface, but not at the interface itself.

Table 1 – RITBA Specimen Test Results

Note that the break in core number 1 traveled around a large piece of angular silaceous aggregate in the substrate. There was no trace of mortar on the stone, indicating a minimal bond to the concrete matrix. That would have reduced the strength of the concrete in that location, resulting in the fracture. Core number 4 failed in the preloading of the specimen (so no loading rate is provided), but that appears to be anomalous behavior. It did, however, fail through the patch/substrate interface. Aside from number 4, the range of breaks was rather small, given the variables involved. Treating number 4 as an outlier, the mean was 173 psi (417 lbs), the standard deviation was 16 psi (38.4 lbs) and with a 95% confidence level of 20 psi (48 lbs). Neglecting number 1 changes the values only slightly and is therefore not seen to have a significant effect, indicating that the core would likely have broken in the interface within the range of the other specimens, if it had not failed where it did.

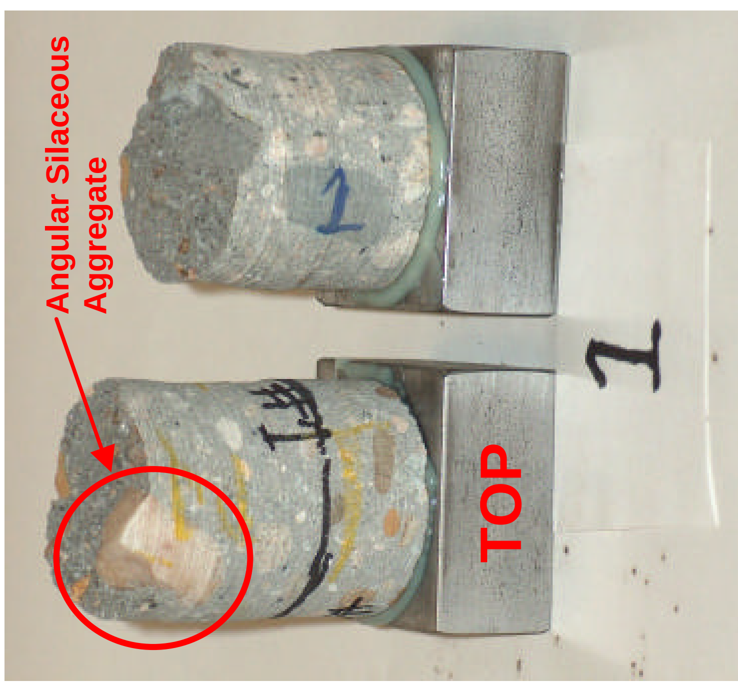

Figure 17 – Core 1 Break

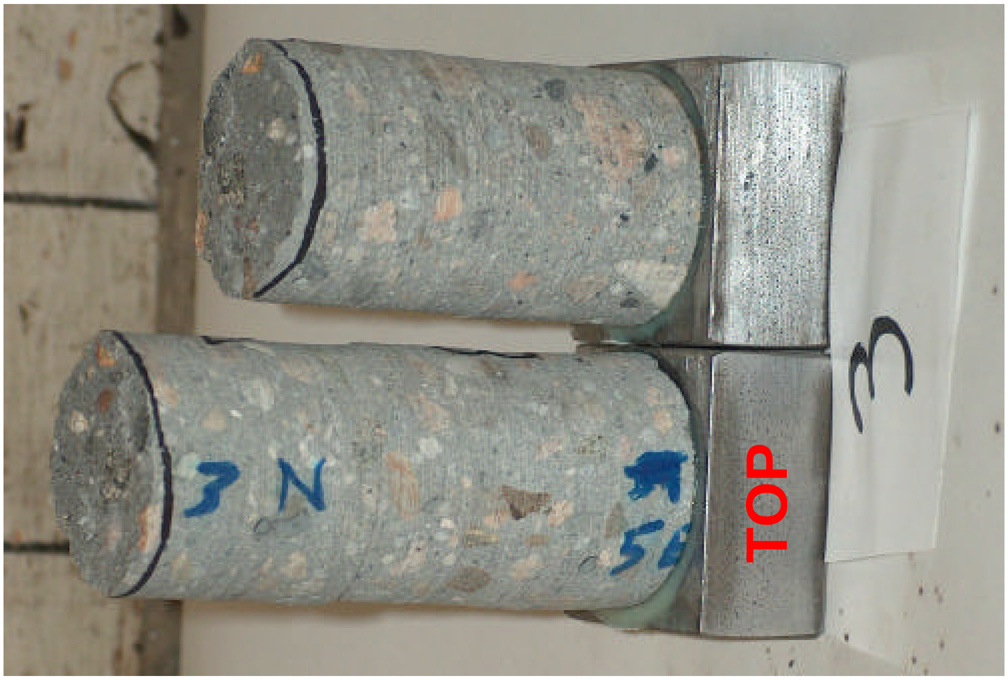

Figure 18 – Core 3 Break

Figure 19 – Core 4 Break

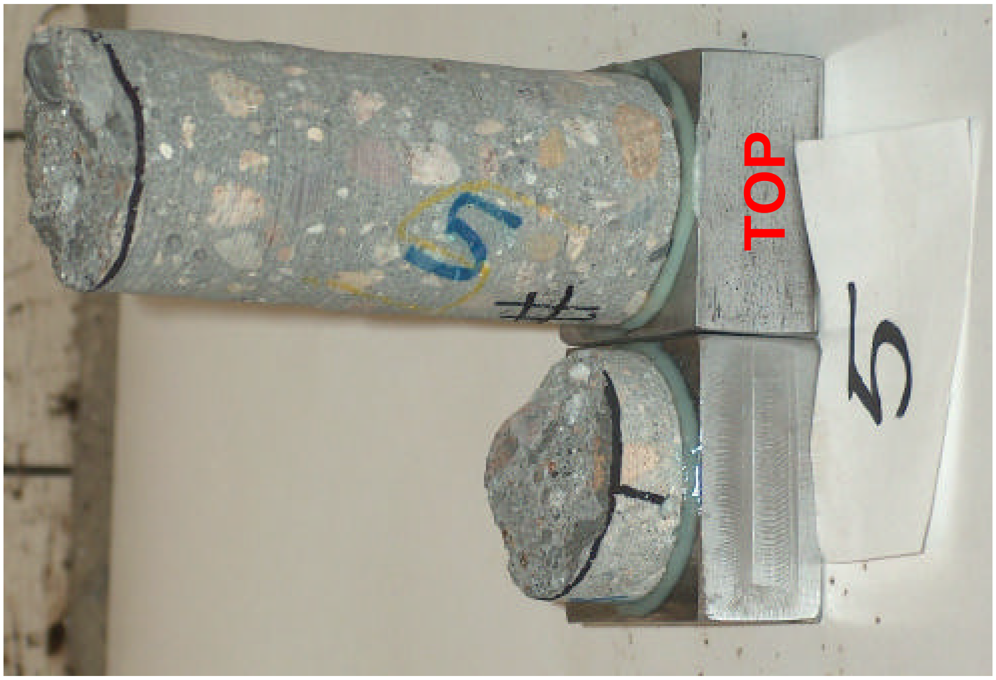

Figure 20 – Core 5 Break

Figure 22 – Core 9 Break

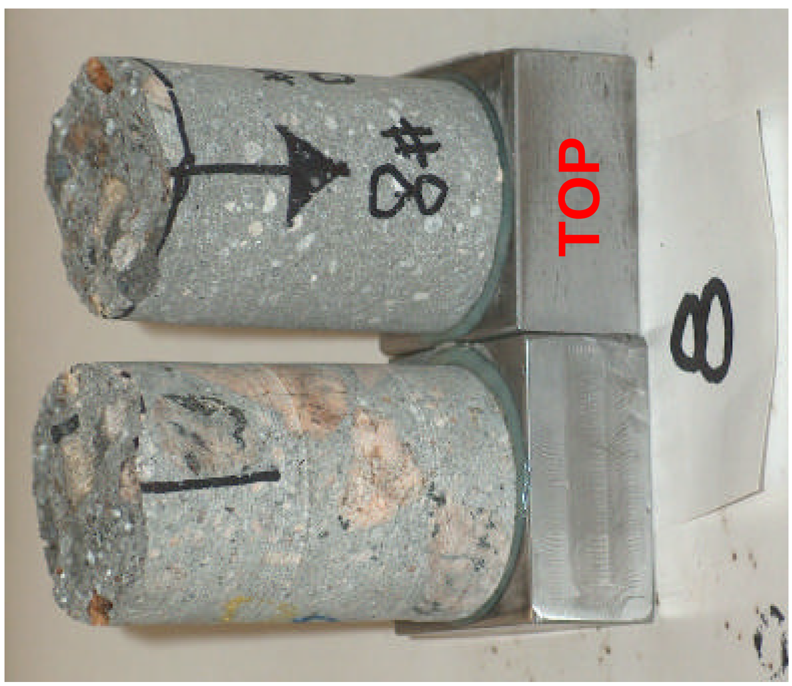

Figure 21 – Core 8 Break

Conclusions

Since the testing was treated as a blind, it was not known until after the test which specimens were from the areas of concern, although it was understood that there were three of each condition. Since five of the six failed at nearly the same load and it seems as though all six might have failed through the interface plane[8], it could not be determined from the test values obtained which repair locations were not patched using the product manufacturer's recommended procedure. Because of that, it seems safe to conclude that there is no significant difference between the tensile strength of the cores in the sample set. The bond strength of all the specimens would therefore be at least as high as the tensile strength measured. The relatively low strength failure of number 4 might indicate a deficiency at that location, but if so, it would appear to be atypical of the repairs in general.

It was disclosed after testing was concluded that cores 5, 8 and 9 were from the suspect locations. So 1, 3 and 4 would be expected to have had higher tensile strengths if there was a deficient bond in the suspect regions. But core 4 failed as though the substrate had not been properly prepared (based on the family of test results). And the highest tensile capacity occurred in core 8, although that may be another atypical result. The average for the SSD specimens was a tensile strength of 166 psi and 177 psi for the other set. This is close enough that it does not alter the conclusion that all of the cores have similar tensile strengths.

It is important to realize that this is a small sample size statistically and that reduces the degree of confidence in the results. However, given the variability of the samples, the consistency of the results would suggests that the population (the repaired locations on the piers) would be fairly uniform in performance.

Typically, the ideal for tensile failure for a repair material is for it to occur in the substrate. This would mean the weakest point is the original concrete. But with the exception of core number 1, the failures were through the plane of the interface. Both the repair material and the substrate fractured in each of the other specimens. This can be seen in photos of the breaks, particularly by noting how the fracture passes through the line marked to show the interface. Since the breaks did not separate cleanly at the

[8] If not for the failure in the substrate of core number 1, as noted previously

interface, it suggests a stress concentration probably due to dissimilar materials and aggregate effects, rather than a direct failure of the bond between the materials.

As noted in the Introduction, this was a comparative study, using the SSD specimen set as the control. The test method used cannot be directly compared to the standards employed by the manufacturer in creating the product specifications, so the results have no bearing in reference to those specifications. If the repairs prepared using an SSD substrate are considered acceptable, the repairs without SSD should be adequate as well, as determined within the scope of the testing performed for this study.